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ABSTRACT

Safeguards have been applied to the R&D process for directly fabricating CANDU fuel with PWR spent fuel material. Safeguards issues to be resolved were identified in the areas such as international cooperation on handling foreign origin nuclear material, technology development of operator's measurement system of the bulk handling process of spent fuel material, and a built-in C/S system for independent verification of material flow. The fuel cycle concept (Direct Use of PWR spent fuel in CANDU, DUPIC) was developed in consideration of reutilization of over-flowing spent fuel resources at PWR sites and a reduction of generated high level wastes. All those safeguards issues have been finally resolved, and the first batch of PWR spent fuel material was successfully introduced in the DUPIC lab facility and has been in use for routine process development.

INTRODUCTION

DUPIC(Direct Use of PWR spent fuel in CANDU) has been known in the international nuclear community for 10 years since it was introduced by KAERI, Korea, and now it has almost become a common name as one of the alternative nuclear fuel cycle technologies. Although it has not yet a proven technology its uniqueness and creativeness compared to others like reprocessing and MOX fuel cycle are certainly well recognizable.

It is not unusual for Korea to come up with the concept of the DUPIC fuel cycle knowing that Korea has strategically two types of power generating reactors (PWR and CANDU)(Fig.1) and their spent fuel generated is accumulating rapidly in the onsite spent fuel storage pits[ref.1](Table 1). In addition, there is no definite fuel cycle option for the utilization of resources remaining in spent fuel except that a plan to build interim storage facility by 2016 and related R&D work with no hot material involvement.

DUPIC was first introduced at the meeting of the ROK-US Joint Standing Committee on Nuclear Energy Cooperation (JSCNEC) in early 1991 in an effort of looking into fuel cycle technology that would not be implicated with international non proliferation policy in using plutonium bearing spent fuel material. Subsequently, with a favorable international consensus, the DUPIC project could go on with the feasibility study on several options of the DUPIC process and its safeguardability. At this time the project manager at KAERI proposed to form an international project coordinating group called “Project Review Meeting (PRM)” among KAERI, AECL, US DOS, and IAEA which had common interests in DUPIC fuel cycle development. It was effectively run twice a year to resolve technical and administrative issues raised in the course of further advancement of the DUPIC project. In this PRM two separate studies were done. One was from KAERI and AECL which concentrated on selection of the most probable item such as the DUPIC process line under the condition of not changing the existing CANDU reactor design, and the other came from LANL of the US on the safeguardability of the DUPIC process. The conclusions from both studies were that the OREOX (Oxidation and Reduction of Oxide fuel) process was the only process which met the selection criteria more closely than the others did and its safeguarding would be possible with a few limitations.

Safeguards responsibility at this point was to create a total system that satisfies the obligations required by both the US and IAEA in having access to handling spent fuel and measurement of the bulk form of spent fuel. As for the US obligations, DUPIC project needed to produce justifiable source information and data in the form of report to satisfy the US to lead to ROK-US Joint Determination, commonly known as the prior consent clause of alteration in form and content of irradiated US origin fuel. In the case of the IAEA, the DUPIC facility needed to come up with a viable measurement system for process material accounting, and to provide a means of maintaining the continuity of knowledge of the process material flow, with which the IAEA could develop its own facility specific DUPIC safeguards approach.

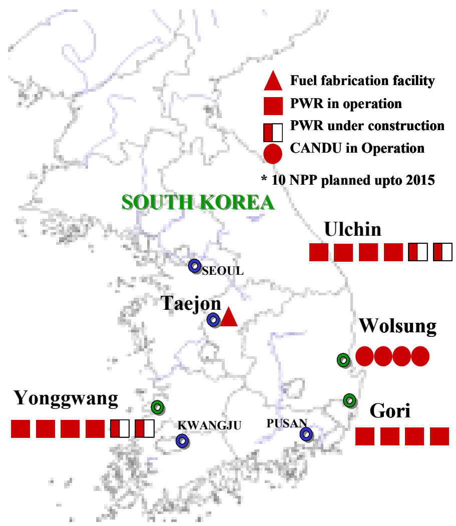

Fig. 1 Korea Nuclear Power Program

Table 1. Cumulative Spent Fuel Arisings in Korea

Unit: MTHM

Year	PWR		CANDU		Total	
	Annual	Cumul.	Annual	Cumul.	Annual	Cumul.
1997		1,823		1,410		3,233
2000	203	2,376	376	2,256	579	4,632
2005	258	3,518	376	4,136	634	7,654
2010	332	5,067	376	6,016	708	11,083
2015	464	7,177	282	7,708	746	14,885

After about 10 years of technology development and closer international cooperation with the US, AECL and the IAEA DUPIC project has finally come to the point where hot material was introduced in the DUPIC process and has been in normal use.

DUPIC FUEL CYCLE TECHNOLOGY IN GENERAL

A CANDU reactor has the outstanding capability of obtaining the maximum energy from thermal fission of natural uranium [ref.2]. The low neutron absorption of heavy water coolant and the moderator allows the use of natural uranium and slightly enriched uranium. The foundation of the DUPIC fuel cycle rests on its fuel cycle flexibility and the synergism between PWRs and CANDUs, and uses dry processing technology to manufacture CANDU fuel directly from spent PWR fuel. The fissile contents in spent PWR fuel is sufficient enough to be burned again in a CANDU reactor (Fig. 2).

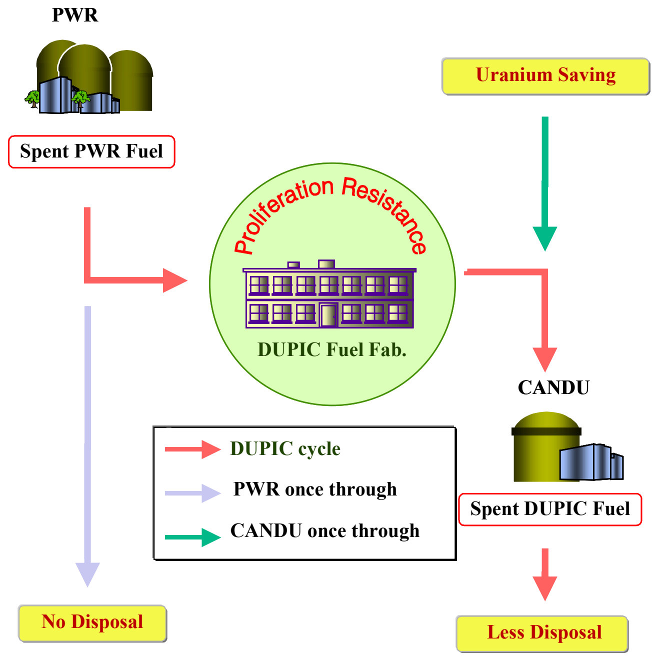

Fig. 2 DUPIC Fuel Cycle Concept

The DUPIC fuel fabrication process begins with dismantling the spent PWR assembly to obtain rod cuts of a specified size depending on the process equipment available. The rod cuts are then declad by using a mechanical and/or thermal method. The decladed material is subject to the OREOX process, that is, thermal cycling of Oxidation and Reduction at a temperature of about 450°C in air and about 700°C in an argon and 4□ hydrogen atmosphere, respectively. The OREOX process causes crystallographic transformations in the pellet matrix which makes the pellets break into a finer power. Once the powder is conditioned to improve its sinterability, the rest of the process is similar to the conventional CANDU fuel fabrication process, except that all of processing activities are remotely handled in a hot cell (Fig. 3).

DUPIC laboratory currently is in hot operation with one batch (about 2 Kg) of spent PWR fuel and has produced about 50 pellets and three test elements being irradiated in HANARO research reactor in KAERI, Korea. Post irradiation examination of the three test elements is scheduled in 2nd half of the year 2000.

SAFEGUARDS SYSTEM DEVELOPMENT AND IMPLEMENTATION

The safeguards system with regard to DUPIC fuel cycle has faced many issues to cope with, namely: 1) there was no directly applicable NDA measurement technology for facility accounting for spent fuel material due to high radiation and fission product interference, 2) there was no DUPIC specific safeguards criteria available in the IAEA reference publication, and 3) there were no appropriate methods as a C/S system for the positive identification of material movement in and out of the hot cell in a shielded cask. Those issues were conceptually resolved by the recommendations that appeared in a state of art report " Safeguardability of Direct Use of Spent PWR Fuels in CANDU Reactors" published by the Los Alamos National Laboratory(LANL) in October, 1992[ref.3]. Based on the report and some other references, the DUPIC safeguards R&D group could summarize the technology necessary for process material accounting as follows: (1) neutron coincident counting methodology could be one alternative fabrication facility in Japan, (2) a Near Real Time Accountability system would be required due to the inaccessibility to process material under a high radiation environment, and lastly (3) an unattended continuous monitoring system comprised of radiation detection and image recording would be built into the system to maintain continuity of the knowledge of material flow as a dual C/S system.

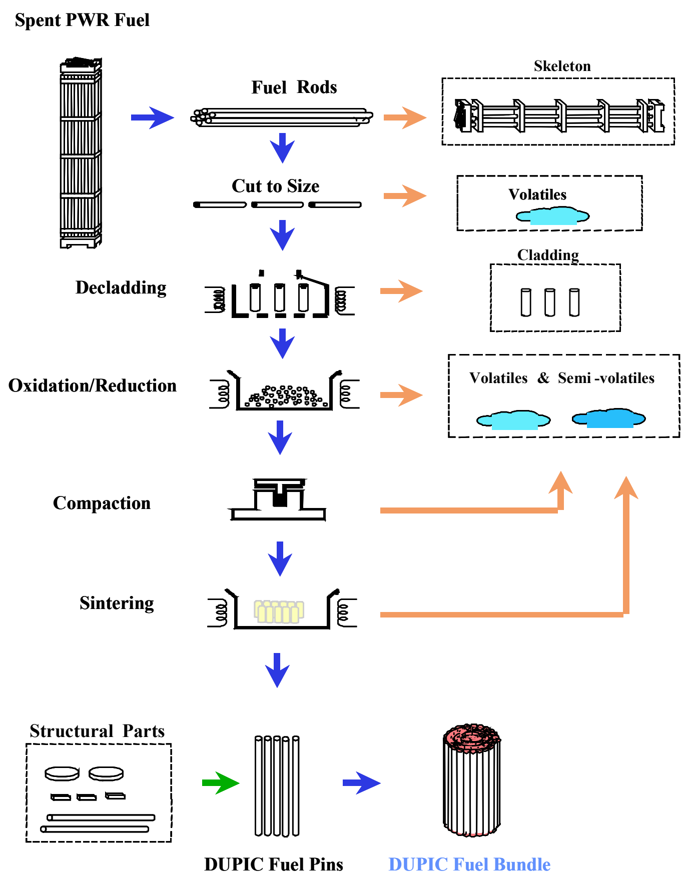

Fig. 3 DUPIC Fuel Fabrication Process

Conceptual Design of the Safeguards System

In the design of the safeguards system of the entire DUPIC fuel cycle, a survey has to take place to identify the flow of material, the relevant labs or facilities involved, the means of securing process material, and process descriptions.

The DUPIC input material as an assembly is originally transferred from the PWR site to the Post Irradiation Examination Facility at the KAERI site, where the assembly is dismantled to get a pre-selected rod or rods. The whole rod is cut in pieces in a specified length to fit into the process line. The rod cuts are then transferred to the DUPIC facility, where they are processed and fabricated into DUPIC irradiation samples or bundles, which, eventually move to HANARO research reactor for fuel integrity and performance tests or a CANDU reactor for field tests of fuel performance.

Accountability System of the DUPIC Fuel Cycle

In establishing the accountability system of DUPIC activities there are two modes of operation. One mode is to carry out a lab scale of the facility aimed to produce sample fuel pins for irradiation in a research reactor. The other one is to produce fuel bundles for a larger commercial power plant. Whichever the mode is, there are four different nuclear facilities, (possibly five facilities if a waste processing facility is available) involved to serve the DUPIC fuel cycle, namely, PWR, PIEF(Post Irradiation Examination Facility), DFDF (DUPIC Fuel Development Facility), HANARO or CANDU reactor, and RWTF (Radioactive Waste Treatment Facility) as seen in Fig. 4.

As for the accounting method, PWR, PIEF, and the reactors are considered to be item counting facilities and DFDF and RWTF are bulk measurement facilities. Normally, item facilities need to account for nuclear materials based on the burn up data and code calculations. The bulk facilities need to account for nuclear material by weighing, chemical analysis of representative samples, and/or NDA measurement. In the case of DUPIC process line, the NDA method is adapted to account for the entire process material. In order to maintain data coherence and material balance between item facilities and bulk handling facilities, and also to remove Shipper/ Receiver Difference occurrence , the Curium Ratio method is introduced to account for DUPIC process material, in which accounting data from the item facility is normalized to the NDA measurement data in DFDF provided that the NDA measurement system is authenticated by the IAEA. Under the Curium Ratio method all of the internal measurements on samples are done with one instrument called the DSNC (DUPIC safeguards neutron counter or Curium Boy as a nick name)[ref. 4] (Fig. 5&6).

INTERNATIONAL SAFEGUARDS COOPERATION

During DUPIC fuel cycle development, international cooperation played a very important role in such areas as development of an IAEA safeguards approach, and timely conclusion of ROK-US Joint Determination. In order to have a better quality of IAEA safeguards the operator side suggested that the construction of process built-in C/S system should be installed from the design stage to facilitate IAEA independent verification activities and also to minimize interference of normal facility operation. For that purpose, facility operators accepted the authentication of process measurement system by installing an IAEA instrument calibration source and allowing the raw signal of the measurement data to be routed directly to an IAEA monitoring station. In addition, operator and IAEA agreed to have either a surveillance camera or seals on all un-monitored openings of the DUPIC facility. One important incentive which operators very much appreciated was the early issue of the DFDF Facility Attachment, even though the process equipment installation was not completed, therefore, it was not ready for accepting ad hoc inspection or on-site design information verification. That document was a prerequisite for applying for the ROK-US Joint Determination of using US origin spent fuel material.(Fig. 7&8).

One of the critical issues with the US in relation with the DUPIC project was to secure the necessary quantity of spent fuel material subjected to bilateral agreement between ROK and the US. DUPIC was technically required to demonstrate safeguardability on US origin material. To achieve this goal, DUPIC needed to have the measurement technology that was available at the Los Alamos National Laboratory (LANL). Close cooperation between KAERI and LANL led to the preparation of the document necessary for Joint Determination process.

THE CURRENT STATUS OF DUPIC SAFEGUARDS IMPLEMENTATION

The first shipment of DUPIC process material as one batch was introduced from PIEF on Jan. 27, 2000 after the selected PWR rod was cut in 25 cm long pieces, measured by NDA and calculated by the Origen Code to obtain the quantity of nuclear material as such U element, U-235 isotope, and Pu element.

Immediately after transfer to DFDF, the whole batch was measured with Curium Boy to get the Curium total, and the Curium Ratio was then established for each type of nuclear material. These Curium Ratios are maintained until the specific batch operation is finished.

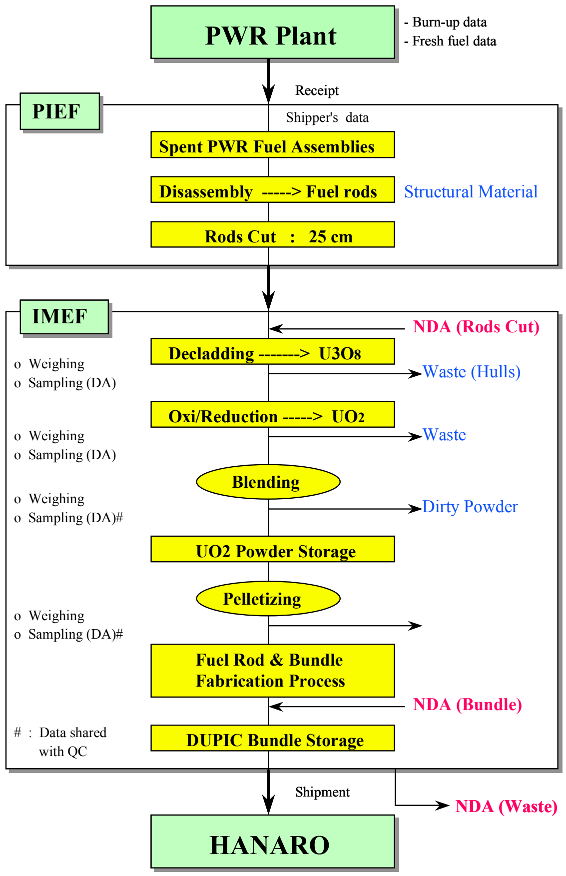

Fig. 4 DUPIC Process Diagram and Spent Fuel Safeguards Plan

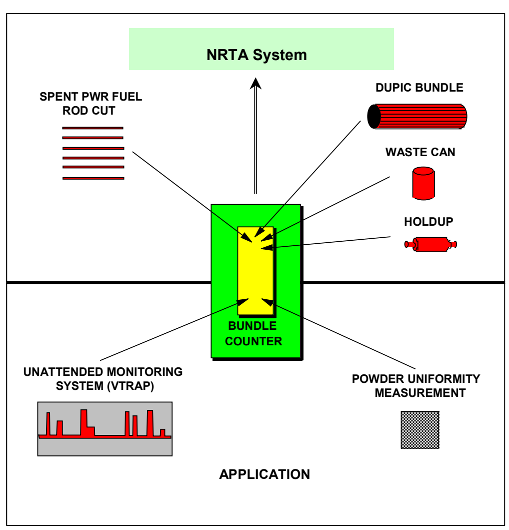

Fig. 5 Safeguards Data Control by Curium Measurement

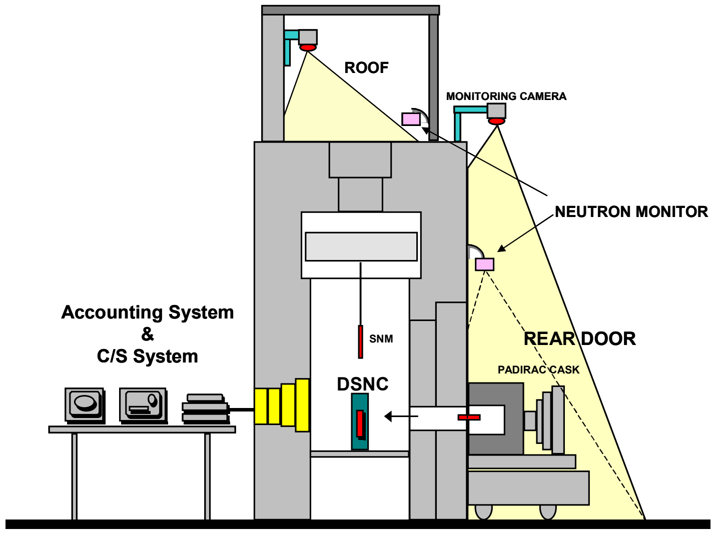

Fig. 6 DFDF Safeguards System

$$\text{Cm ratio} = \frac{\text{Mass of U235, U element or Pu element}}{\text{Cm Mass}}$$

Where, mass of U235, U element or Pu element is derived from burnup simulation by ORIGEN code in which specific burnup is determined by Gamma scanning. The Cm mass is measured by DSNC as follows;

$$m(Cm) = \frac{R(Cm)}{k}$$

Where, R is double rate, and k is a calibration constant (1.19 x 10^5) obtained from performance test

SNM mass = Cm mass (measured by DSNC) x Cm ratio

< Real data of mini-element #1 for irradiation in HANARO >

Cm ratio (batch G23-G2A)	Pu/Cm	297.72
	U235/Cm	240.12
	U/Cm	31400.95
Average Double rate (cps) measured by DSNC		151.601
Cm mass		0.00127
Declared SNM	Pu	0.378 g
	U235	0.305 g
	U	39.879 g

Fig. 7 Example of Nuclear Material Account

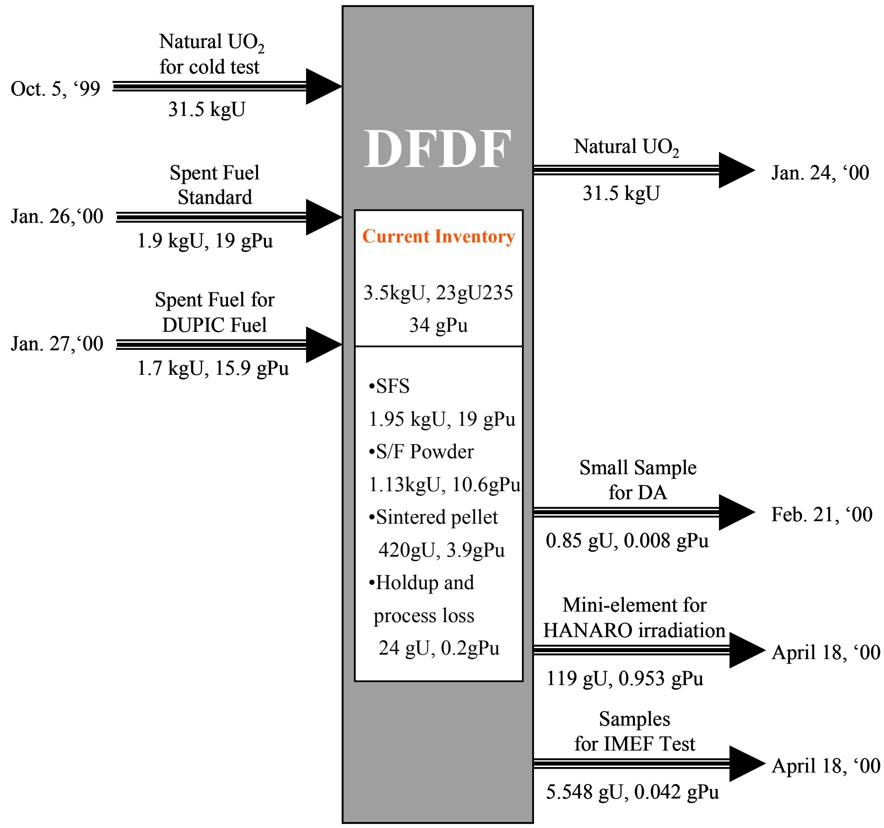

Fig. 8 Inventory Status in DFDF

CONCLUSION

A lab scale DUPIC facility safeguards system was successfully established with active support from the IAEA and US under the international cooperation program, and has been in routine hot operation since the first batch of spent fuel was introduced in DFDF. With the experience gained from the lab scale facility and further advancement of safeguards technology development, a model safeguards system for the pilot scale facility is foreseen in the very near future.

REFERENCES

[1] LEE, JS, PARK, HS, KIM, BK, GADSBY, RD, "Burn Again and Less By DUPIC", Proc. 11th KAIF/KNS Annual Meeting, Seoul, Korea, Oct. 1994.

[2] YANG, MS, PARK HS, "Characteristics and Status of DUPIC Fuel Cycle Development", June 2000.

[3] PILLAY, KKS, MENLOVE, H, PICARD, RR, "Safeguardability of Direct Use of Spent PWR Fuels in CANDU Reactors", LA-12432-MS, Oct. 1993.

[4] LEE, YG, CHA, HR, HONG, JS, MENLOVE, H, RINARDS, P, "Development of DUPIC Safeguards Neutron Counter", 38th INMM, Phoenix, USA, July 1998.